



## Aquaculture Reports

journal homepage: [www.elsevier.com/locate/aqrep](http://www.elsevier.com/locate/aqrep)Effects of hydrothermal processing on nutritional value of *Canavalia ensiformis* and its utilization by *Clarias gariepinus* (Burchell, 1822) fingerlingsV.T. Okomoda<sup>a,\*</sup>, L.O. Tiamiyu<sup>b</sup>, S.G. Uma<sup>a</sup><sup>a</sup> Department of Fisheries and Aquaculture, University of Agriculture, Makurdi, Nigeria<sup>b</sup> Department of Aquaculture and Fisheries, University of Ilorin, Kwara State, Nigeria

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## ABSTRACT

Jack bean (*Canavalia ensiformis*) is one of the underutilized legumes in animal feed production partly because of its high antinutritional factors. This study investigated the nutritional value of *C. ensiformis* seed subjected to hydrothermal processing in the diet of the African catfish *Clarias gariepinus*. Five batches of *C. ensiformis* seeds were hydrothermally processed in boiling water (100 °C) for 0, 10, 20, 30 and 40 min, respectively. Proximate composition of the seed showed no significant effect of hydrothermal processing on protein and fat content of *C. ensiformis*. However, all essential amino acids were significantly affected. The anti-nutritional factor canavanine was not markedly reduced even at 40 min hydrothermal processing. Fifty fingerlings of *C. gariepinus* (1.07 ± 0.01 g) were stocked in 15 hapas measuring 1 × 1 × 1 m<sup>3</sup>, labeled in triplicate according to five isonitrogenous diets (35% CP) formulated using the processed *C. ensiformis* seed at an inclusion level of 27%. The highest body weight gain (2.73 g), specific growth rate (2.26 g day<sup>-1</sup>), feed conversion efficiency (34.11%) and protein efficiency ratio (0.078) were observed at hydrothermal treatment of 30 and 40 min. Hydrothermal processing of *C. ensiformis* up to 40 min could be exploited in the commercial and on-farm production of catfish diet at 27% level of inclusion.

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## 1. Introduction

The main nutrients in animal nutrition are protein and energy. Many legumes such as soybean, groundnut, and cowpea have been fully exploited as conventional feed stuffs for animal feed formulation. However, the dwindling supply and increasing prices of these feedstuffs have necessitated research into other substitutes of protein for animal nutrition (Tiamiyu et al., 2015a). Many lesser known legumes with potential for exploitation in animal feeds are currently not utilized or underutilized, including legumes such as *Sphenostylis stenocarpa*, *Mucuna cochinchinensis*, *Mucuna flagellipes* (Ndidi et al., 2014), *Mucuna utilis*, *Canavalia ensiformis* (Afolabi et al., 1985; Ezeagu et al., 2003; Tuleun et al., 2009; Tiamiyu et al., 2015b). Compared to cereals, the seeds of these legumes have high protein and are of low cost, and possess a well-balanced profile of essential amino acids (Vijayakumari et al., 1997). Despite this, their inclusion on a large scale in animal feed industry has been limited by the presence of anti-nutritional factors (Sogbesan

and Ugwumba, 2008; Tiamiyu et al., 2015a). These anti-nutritional factors (e.g. alkaloids, glycosides, oxalic acids, phytates, protease inhibitors, haematoglutinin, saponin, momosine, cyanoglycosides, linamarin) significantly affect growth and other physiological processes at higher inclusion levels (Alegbeleye et al., 2001) and can be removed by conventional processing methods such as toasting, soaking, hydrothermal treatment, and fermentation (Tiamiyu et al., 2015b).

Jack bean of the genus *Canavalia* comprise forty-eight species of these underutilized legumes. They are indigenous to tropical regions where they are widely distributed. They are seldom eaten by humans and yield about 2.5 tons ha<sup>-1</sup> when grown under optimal agronomic conditions (Okonkwo and Udedibie, 1991). Despite their encouraging nutritional composition (Rajaram and Janardhanan, 1992), nutritional trials involving *C. ensiformis* seed meal are limited and the few available data show poor performance of fish (Martinez-Palacios et al., 1998; Akinbiyi, 1992; Abdo de la Parra et al., 1998). All available literature points to the presence of anti-nutritional factors (ANFs) as the principal culprits for the observed poor performance. Some of the previously reported ANFs in jack bean include: concanavalin-A (Con-A), a lectin (MERCK, 1989); canavanine (Rosenthal, 1992); saponins (Belmar and Morris,

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1994a; Belmar and Morris, 1994b); trypsin and chymotrypsin inhibitors (Ologhobo et al., 1993). This present study is therefore designed to determine the nutritional value of *C. ensiformis* after hydrothermal processing and to investigate the effect of the processed products on the growth performance and carcass composition of fingerlings of the African catfish, *Clarias gariepinus*.

## 2. Materials and method

### 2.1. Feed procurement, processing, and analysis

Matured seeds of *C. ensiformis* were collected from Assakio in Lafia Nasarawa State, Nigeria. The seeds were cleaned, milled and stored in a dry place. The other ingredients: soybean meal, yellow maize meal, fishmeal, vitamin and mineral premixes were obtained from the modern market in Makurdi (the Benue State capital). The seeds of soybean were toasted to remove antinutritional factors in the seeds after which they were milled and stored at room temperature. The *C. ensiformis* seeds were divided into five batches and hydrothermally processed for 0, 10, 20, 30 and 40 min at a constant water temperature of 100 °C. The hydrothermally processed seeds were sun-dried and cracked to remove the coat. Samples of processed seeds were sent to the University of Jos for analysis of proximate composition, amino acid profile and phytochemicals. The proximate composition was determined using standard methods (AOAC, 2001) while the amino acid profile was determined using the method described by Spackman et al. (1958). The aim of processing is usually to remove ANFs hence improving nutrient digestibility by animals. To determine the efficacy of the hydrothermal process in reducing the ANFs of jack bean, qualitative analysis was done according to the procedure described by Harborne (1973); Sofowora (1993); Trease and Evans (1989). This analysis method screens sample for availability of various antinutritional factor and qualitatively quantifies them. The remaining processed beans were ground into fine meal and stored for feed formulation. The proximate composition of the formulated diet and of the carcass of the fish before and after the feeding trial were also determined according to AOAC (2001).

### 2.2. Diet formulation

Iso-nitrogenous diets of 35% crude protein were formulated with fishmeal (10.00%), maize meal (17.64%), soybean meal (41.19%), vitamin/mineral premixes (1.5% each), salt/oil (0.50% each) and *C. ensiformis* (27.17%). All ingredients were sieved, weighed and mixed uniformly. Hot water at 60 °C was added to the mixture and stirred to form a dough. The dough was pelleted using a 2mm-die and the resulting pellets sun-dried for three days. The diets were packaged, and stored for use.

### 2.3. Fish procurement, experimental set up and performance evaluation

A nutritional trial was conducted at the research farm of the department of Fisheries and Aquaculture, University of Agriculture Makurdi, Benue State, Nigeria. One thousand fingerlings of *C. gariepinus* were obtained from the University Fish Farm and acclimatized for two weeks before the start of the experiment. Fifteen hapas (for the five treatments with three replicates) measuring 1 × 1 × 1 m<sup>3</sup> were mounted on two-kuralon ropes and set across a 45 × 45 × 2m<sup>3</sup> earthen pond. The ropes were properly staked to the dyke of the pond using bamboo sticks. Metal sinkers were attached to the four bottom corners of each hapa to ensure uniform spread and proper extension, hence, allowing easy inflow and outflow of water through each hapa system. The system was set in such a way that hapas were submerged half way below

the water level to enable easy access to the fish. Hapas were labeled in triplicate according to the five experimental diets to be administered. Pond water quality was maintained by the addition of fresh river water from the River Benue on a daily basis through a network of pipes. Estimated daily water replacement in the pond was about 20%. Water quality parameters such as temperature (26.1 ± 1.5), pH (7.53 ± 0.05), conductivity (543 ± 2.5), total dissolved solids (271.5 ± 6.0) and dissolved oxygen (5.6 ± 0.5) concentration were monitored weekly in the ponds using a digital multi-parameter water checker (Hanna water tester Model HL 98126). Fifteen batches of 50 fingerlings (individual weight approximately 1 g) were weighed and stocked randomly in each of the fifteen hapas.

The fish were hand-fed twice daily (08:00 am and 06:00 pm) at a rate of 5% of the body weight per day and weighed weekly to determine weight gain and adjust feed rations. After feeding the fish for eight weeks, growth rate, survival, and feed and nutrient utilization were assessed.

$$(a) \text{ Growth rate } \left( \frac{g}{d} \right) = \frac{W_2 - W_1}{t_2 - t_1}$$

$$(b) \text{ Specific growth rate } \left( \frac{\%}{\text{day}} \right) = \frac{\log_e(W_2) - \log_e(W_1)}{t_2 - t_1}$$

where  $W_1$  = initial weight (g)

$W_2$  = final weight (g)

$t_2 - t_1$  = duration between  $W_2$  and  $W_1$  (d)

$$(c) \text{ Feed conversion ratio (FCR)} = \frac{\text{dry feed intake}}{W_2 - W_1}$$

$$(d) \text{ Feed efficiency ratio (\%FER)} = \frac{(W_2 - W_1) \times 100}{\text{dry feed intake}}$$

$$(e) \text{ Protein efficiency ratio} = \frac{W_2 - W_1}{\text{protein fed}}$$

$$\text{where protein fed} = \frac{\% \text{protein in diet} \times \text{total diet consumed}}{100}$$

$$(f) \% \text{Survival rate} = \frac{\text{fish stocked} - \text{mortality}}{\text{fish stocked}} \times 100$$

### 2.4. Data analysis

Summary statistics of the different variables measured across the treatment (in triplicate) were obtained using Minitab 14 for Windows (Minitab Inc, State College, Pennsylvania, USA). The treatment means were compared using one-way Analysis of Variance (ANOVA) and where significant differences occurred, means were separated using Fisher's least significant difference at a significance level of  $\alpha \leq 0.05$ .

## 3. Results

### 3.1. Proximate composition of hydrothermally processed *C. ensiformis*

The protein and fat content of the *C. ensiformis* seeds were not significantly affected by hydrothermal processing time (Table 1). Average values of 253 gkg<sup>-1</sup> and 53 gkg<sup>-1</sup> were recorded for protein and fat, respectively across all processing times. However, fibre was significantly reduced from 71 to 52 gkg<sup>-1</sup> as the hydrothermal process was prolonged from 0 to 40 min. The same trend was observed for ash and moisture content.

### 3.2. Essential amino acid profile and anti-nutritional factor of hydrothermally processed *C. ensiformis*

Overall observation revealed a significant reduction in all essential amino acids isolated in this study (Table 2). The severity of

**Table 1**  
Proximate composition (g kg<sup>-1</sup>) of *Canavalia ensiformis* seed using different processing methods. Numbers are means ± standard errors. Mean in the same row with different superscripts differ significantly (ANOVA,  $P \leq 0.05$ ).

Parameters(gkg <sup>-1</sup> )	0 min	10 min	20 min	30 min	40 min
Moisture	72.6 ± 3.1 <sup>a</sup>	71.2 ± 0.5 <sup>b</sup>	70.7 ± 0.1 <sup>c</sup>	68.4 ± 0.1 <sup>d</sup>	65.1 ± 0.1 <sup>e</sup>
Ash	38.9 ± 0.6 <sup>a</sup>	37.6 ± 0.3 <sup>a</sup>	31.2 ± 1.0 <sup>b</sup>	24.4 ± 6.1 <sup>c</sup>	20.1 ± 1.1 <sup>c</sup>
Lipid	52.1 ± 4.1 <sup>a</sup>	53.3 ± 4.1 <sup>a</sup>	54.3 ± 5.1 <sup>a</sup>	51.4 ± 0.1 <sup>a</sup>	52.9 ± 1.1 <sup>a</sup>
Fibre	71.1 ± 5.1 <sup>a</sup>	66.8 ± 5.3 <sup>b</sup>	53.8 ± 1.1 <sup>c</sup>	54.7 ± 5.1 <sup>c</sup>	51.7 ± 6.1 <sup>d</sup>
Protein	252.2 ± 6.0 <sup>a</sup>	255.4 ± 3.1 <sup>a</sup>	255.4 ± 3.1 <sup>a</sup>	251.4 ± 2.2 <sup>a</sup>	251.4 ± 3.2 <sup>a</sup>
NFE	513.2 ± 3.1 <sup>d</sup>	537.2 ± 3.1 <sup>b</sup>	527.2 ± 0.1 <sup>c</sup>	559.8 ± 3.1 <sup>a</sup>	561.8 ± 0.1 <sup>a</sup>

Key: NFE = nitrogen free extract.

**Table 2**  
Essential amino acid composition (g/100 g protein) of *Canavalia ensiformis* seed using different processing methods. Numbers are means ± standard errors. Mean in the same row with different superscripts differ significantly (ANOVA,  $P \leq 0.05$ ).

Parameters (g/100 g protein)	0 min	10 min	20 min	30 min	40 min
Lysine	6.54 ± 0.05 <sup>a</sup>	6.51 ± 0.04 <sup>a</sup>	5.98 ± 0.21 <sup>b</sup>	5.78 ± 0.21 <sup>c</sup>	5.68 ± 0.01 <sup>c</sup>
Histidine	2.61 ± 0.01 <sup>a</sup>	2.58 ± 0.03 <sup>a</sup>	2.49 ± 0.02 <sup>b</sup>	2.47 ± 0.12 <sup>b</sup>	2.39 ± 0.30 <sup>c</sup>
Methionine	1.02 ± 0.21 <sup>a</sup>	0.92 ± 0.02 <sup>bc</sup>	0.95 ± 0.31 <sup>b</sup>	0.92 ± 0.21 <sup>bc</sup>	0.90 ± 0.41 <sup>c</sup>
Threonine	3.49 ± 0.31 <sup>a</sup>	3.48 ± 0.11 <sup>a</sup>	3.45 ± 0.21 <sup>b</sup>	3.43 ± 0.13 <sup>bc</sup>	3.41 ± 0.06 <sup>c</sup>
Isoleucine	3.23 ± 0.01 <sup>a</sup>	3.21 ± 0.02 <sup>a</sup>	3.19 ± 0.10 <sup>b</sup>	3.10 ± 0.04 <sup>c</sup>	3.11 ± 0.51 <sup>c</sup>
Leucine	7.05 ± 0.05 <sup>a</sup>	6.98 ± 0.01 <sup>b</sup>	6.89 ± 0.12 <sup>c</sup>	6.87 ± 0.32 <sup>c</sup>	6.88 ± 0.04 <sup>c</sup>
Tyrosine	3.19 ± 0.03 <sup>a</sup>	3.11 ± 0.54 <sup>b</sup>	3.11 ± 0.21 <sup>b</sup>	3.01 ± 0.21 <sup>c</sup>	2.91 ± 0.11 <sup>d</sup>
Valine	4.23 ± 0.11 <sup>a</sup>	4.21 ± 0.41 <sup>a</sup>	4.15 ± 0.51 <sup>b</sup>	4.09 ± 0.11 <sup>c</sup>	4.05 ± 0.20 <sup>d</sup>
Phenylalanine	5.22 ± 0.24 <sup>a</sup>	5.15 ± 0.15 <sup>b</sup>	5.13 ± 0.09 <sup>b</sup>	5.13 ± 0.10 <sup>b</sup>	5.03 ± 0.31 <sup>c</sup>
Cystine	1.07 ± 0.41 <sup>a</sup>	0.98 ± 0.01 <sup>b</sup>	0.99 ± 0.04 <sup>b</sup>	0.97 ± 0.11 <sup>b</sup>	0.98 ± 0.50 <sup>b</sup>

**Table 3**  
Qualitative analysis according to Harborne (1973); Sofowora (1993); Trease and Evans (1989) of the presence of some anti-nutritional component in hydrothermally processed *Canavalia ensiformis* seed.

Parameters	0 min	10 min	20 min	30 min	40 min
Lectin	++ve	+ve	+ve	+ve	+ve
Saponins	++ve	++ve	++ve	+ve	+ve
Trypsin	++ve	++ve	+ve	+ve	+ve
Canaviline	++ve	++ve	++ve	++ve	++ve

+ve = present, ++ve = highly present.

**Table 4**  
Proximate composition (g kg<sup>-1</sup>) of the diets fed to *Clarias gariepinus* fingerlings. Numbers are means ± standard errors. Mean in the same row with different superscripts differ significantly (ANOVA,  $P \leq 0.05$ ).

Parameters	0 min	10 min	20 min	30 min	40 min
Crude Moisture	64.7 ± 2.10 <sup>a</sup>	57.1 ± 5.00 <sup>b</sup>	56.6 ± 11.0 <sup>c</sup>	52.4 ± 4.10 <sup>e</sup>	53.5 ± 0.30 <sup>d</sup>
Crude Ash	96.7 ± 3.10 <sup>a</sup>	88.7 ± 4.10 <sup>b</sup>	86.9 ± 1.10 <sup>c</sup>	86.9 ± 3.10 <sup>c</sup>	84.6 ± 0.40 <sup>d</sup>
Fat	56.2 ± 0.30	56.9 ± 3.10	56.7 ± 3.40	56.7 ± 0.50	56.1 ± 0.50
Crude Fibre	60.9 ± 5.10 <sup>b</sup>	61.2 ± 0.90 <sup>a</sup>	58.6 ± 3.20 <sup>d</sup>	58.9 ± 4.10 <sup>c</sup>	61.1 ± 0.30 <sup>ab</sup>
Crude Protein	352.2 ± 6.10 <sup>a</sup>	351.1 ± 3.10	359.5 ± 4.10	350.7 ± 0.50	350.9 ± 2.10
NFE	372.4 ± 0.30 <sup>c</sup>	389.1 ± 0.10 <sup>b</sup>	379.8 ± 3.00 <sup>c</sup>	394.0 ± 0.40 <sup>a</sup>	393.9 ± 4.20 <sup>a</sup>

Key: NFE = nitrogen free extract.

reduction increased with increasing hydrothermal processing time. Four ANFs were isolated in this study: lectin, saponins, trypsin and canavanine (Table 3). Qualitative analysis revealed high levels of all these anti-nutrients in raw *C. ensiformis*. The levels of lectin were markedly reduced after 10 min while those of trypsin were reduced after 20 min of hydrothermal exposure. Saponin was reduced after 30 min. However, the levels of canavanine remained unaffected even after 40 min of hydrothermal exposure (Table 4).

### 3.3. Growth performance and nutrient utilization by *C. gariepinus* fed hydrothermally processed *C. ensiformis* seed meal

Growth performance of *C. gariepinus* and nutrient utilization improved with increasing hydrothermal treatment (Tables 5 and 6). Inclusion of 27% hydrothermally processed *C. ensiformis* at 30 and 40 min gave the best performance in terms of final weight (3.74 and 3.82 g, respectively), weight gain (2.68 and 2.73 g), growth rate

(0.048 and 0.049 g day<sup>-1</sup>), specific growth rate (2.26 and 2.24% day<sup>-1</sup>), feed efficiency ratio (32% and 34%) and protein efficiency ratio (0.076 and 0.078). Feed conversion ratio was higher in fish fed raw *C. ensiformis* (4.16) compared to those fed processed *C. ensiformis* inclusion. Survival, however, did not differ significantly among the dietary treatments. Carcass analysis data (Table 6) revealed increased protein and fat content as the hydrothermal processing time increased.

## 4. Discussion

### 4.1. Proximate composition

Generally, improving nutritional utilization of the diet is the ultimate aim of processing of animal feedstuffs. When heat is involved in processing, the optimum time for processing needs to be determined as overheating can denature certain feed compo-

**Table 5**

Nutritional indices of *Clarias gariepinus* (initial weight of  $1.02 \pm 0.43$ ) fed hydrothermally processed jack bean for 56 days. Numbers are means  $\pm$  standard errors. Mean in the same row with different superscripts differ significantly (ANOVA,  $P \leq 0.05$ ).

Parameters	0 min	10 min	20 min	30 min	40 min
Final weight (g)	$2.53 \pm 0.03^c$	$3.16 \pm 0.03^b$	$3.28 \pm 0.20^b$	$3.82 \pm 0.23^a$	$3.74 \pm 0.07^a$
Weight gain (g)	$1.45 \pm 0.02^c$	$2.08 \pm 0.01^b$	$2.21 \pm 0.03^b$	$2.73 \pm 0.23^a$	$2.68 \pm 0.07^a$
Growth rate ( $\text{g day}^{-1}$ )	$0.025 \pm 0.01^c$	$0.037 \pm 0.003^b$	$0.039 \pm 0.004^b$	$0.048 \pm 0.01^a$	$0.049 \pm 0.01^a$
SGR (%/day)	$1.51 \pm 0.01^c$	$1.92 \pm 0.01^b$	$2.00 \pm 0.06^b$	$2.26 \pm 0.03^a$	$2.24 \pm 0.12^a$
FCR	$4.16 \pm 0.08$	$3.29 \pm 0.06$	$3.32 \pm 0.03$	$3.10 \pm 0.01$	$2.95 \pm 0.25$
FER (%)	$24.05 \pm 0.44^b$	$30.42 \pm 0.59^a$	$30.08 \pm 0.25^a$	$32.24 \pm 0.08^a$	$34.11 \pm 2.93^a$
PER	$0.041 \pm 0.01^c$	$0.059 \pm 0.01^b$	$0.063 \pm 0.007^b$	$0.076 \pm 0.002^a$	$0.078 \pm 0.007^a$
Survival (%)	$97.50 \pm 2.50$	$92.50 \pm 2.50$	$95.00 \pm 0.00$	$92.50 \pm 2.50$	$95.00 \pm 0.00$

Keys: SGR = specific growth rate, FCR = feed conversion ratio, PER = protein efficiency ratio.

**Table 6**

The proximate composition (% of dry matter) of carcass of fingerlings of *Clarias gariepinus* fed diets with hydrothermally jack beans. Mean Numbers are means  $\pm$  standard errors. Mean in the same row with different superscripts differ significantly (ANOVA,  $P \leq 0.05$ ).

Parameters (%)	Initial	0 min	10 min	20 min	30 min	40 min
Moisture	$55.81 \pm 0.21^f$	$57.76 \pm 0.11^e$	$57.81 \pm 0.21^d$	$57.84 \pm 0.01^c$	$58.02 \pm 0.05^a$	$57.96 \pm 0.05^b$
Crude Ash	$1.63 \pm 0.30^e$	$1.78 \pm 0.01^d$	$1.82 \pm 0.30^b$	$1.79 \pm 0.03^c$	$1.87 \pm 0.03^a$	$1.76 \pm 0.03^d$
Fat	$1.93 \pm 0.01^d$	$1.97 \pm 0.51^c$	$2.06 \pm 0.21^b$	$2.06 \pm 0.04^b$	$2.14 \pm 0.01^a$	$2.12 \pm 0.00^a$
Crude Fibre	$1.31 \pm 0.04^d$	$1.46 \pm 0.02^c$	$1.56 \pm 0.61^a$	$1.57 \pm 0.01^a$	$1.49 \pm 0.00^b$	$1.51 \pm 0.07^b$
Crude Protein	$14.18 \pm 0.01^e$	$15.89 \pm 0.41^d$	$16.13 \pm 0.50^c$	$16.14 \pm 0.00^c$	$16.43 \pm 0.02^a$	$16.26 \pm 0.04^b$
NFE	$25.15 \pm 0.51^a$	$21.15 \pm 0.03^b$	$20.64 \pm 0.03^c$	$20.61 \pm 0.02^c$	$20.06 \pm 0.03^c$	$20.40 \pm 0.02^d$

Key: NFE = nitrogen free extract.

nents and reduce the nutritional content of the feedstuff (Tiamiyu et al., 2015a). Thermal processing up to 40 min did not significantly affect the protein and fat content of *C. ensiformis* or of the diets formulated using *C. ensiformis*. Ndidi et al. (2014) earlier reported that crude protein and fat of boiled and roasted *S. stenocarpa* seeds were significantly lower compared to the raw material. Audu and Aremu (2011), however, reported significantly higher protein content of processed red kidney bean (*Phaseolus vulgaris* L.), while fat was reported to be reduced with application of various processing methods. The nutritional content of plants is highly variable and the pattern of response to processing differs depending on the nature of the feedstuff, strains, environmental factors and processing method, hence the differences between the results of the present study and the cited literature. This study also revealed a reduction in fibre content of *C. ensiformis* as the time of hydrothermal processing was increased, probably due to conversion of fibre to simple carbohydrate compounds which are more digestible. Tiamiyu et al. (2015a) reported a similar reduction for hydrothermally processed watermelon seed, suggesting that this was caused by shrinkage which softened and loosened the feed stuff.

#### 4.2. Essential amino acid profile of hydrothermally processed *C. ensiformis*

Heat treatment affects the nutritional value of legumes through protein denaturation caused by overheating (Ullah, 1982). All the essential amino acids in this study reduced significantly with increasing time of hydrothermal processing. Generally, the reduction in the essential amino acids recorded in this study is likely due to denaturation of the amino acids as boiling time increased. The severity of denaturation could be linked to the thermal stability of the different essential amino acids. The levels of valine and tyrosine in processed *C. ensiformis* seed in this study were higher than the values reported for pigeon pea by Akande et al. (2010) and Apata and Ologhobo (1994), despite being significantly reduced as a result of hydrothermal processing. Cereal grain-based diets for fish have been reported to be deficient in lysine, leading to growth reduction (Mostafa et al., 1987; Cheng et al., 2003). The relatively high concentration of lysine in *C. ensiformis* seed makes it a potential sup-

plement in cereal-based fish diets. Leucine in this study was higher than values reported for conventional soybeans (Temple and Aliyu 1994). One of the most important factors that limit large inclusions of conventional and unconventional feedstuffs in the diet of fish is the leucine/isoleucine ratio (Tiamiyu et al., 2013). Feed ingredients that are higher in leucine but lower in isoleucine have been reported to result in an antagonistic response caused by acute deficiency of isoleucine (Crawshaw, 1994). The leucine and isoleucine for all hydrothermally processed *C. ensiformis* observed in this study were higher in value but similar in ratio to reported values in fishmeal (NRC, 1977) and in *Agama agama* meal (Tiamiyu et al., 2014). Values of sulphur-containing amino acids such as methionine and cystine observed for *C. ensiformis* in this study are comparable to those reported for pigeon pea (Akande et al., 2010).

#### 4.3. Anti-nutritional factor of hydrothermally processed *C. ensiformis*

The presence of ANFs in legume seeds has been interpreted as an expression of the chemical warfare of plants against their predators (Carmona, 1996). Consequently, these feeds can only be utilized after some form of processing (e.g. cooking, fermentation, germination, solvent extraction) to increase the bioavailability of the nutrients (Carmona, 1996). Substantial quantities of ANFs have been reported in jack bean seed (MERCK, 1989; Rosenthal 1992; Udedibie and Carlini, 1988; Belmar and Morris, 1994a; Gomez-Sotilo et al., 1993). Protease inhibitors such as trypsin inhibitor present in *C. ensiformis* have been reported to decrease the growth performance of animals (Liener, 1994). The present study demonstrated that the presence of ANFs can be reduced by hydrothermal processing for more than 20 min. Saponins were reduced in 30 min, lectin in 10 min while canavanine was not affected by hydrothermal processing. Qualitative analyses still revealed substantial levels after 40 min of processing. The differences in the response of these ANFs to the processing time is likely due to differences in thermostability. As canavanine is a thermostable, poisonous, alkaline amino acid with a structural analogue of arginine (Rosenthal, 1972; Leon et al. 1989; Osuigwe et al., 2002; Osuigwe, 2003; Osuigwe et al., 2005), other



methods have been devised to remove it from feedstuffs, including soaking in an appropriate solvent (e.g. urea solution) and ensiling prior to processing. Such methods have resulted in a remarkable improvement in the nutritive value of *C. ensiformis* in livestock diet for broilers (Nkwocha, 1988). Therefore, further research is needed in the application of these methods in fish nutrition.

#### 4.4. Growth performance and nutrient utilization of *C. gariepinus* fed hydrothermally processed *C. ensiformis* seed meal

Despite substantial levels of canavanine in hydrothermally processed *C. ensiformis* and significant reduction of essential amino acids, growth performance of *C. gariepinus* fed the diet containing hydrothermally processed *C. ensiformis* was significantly improved with increased hydrothermal processing time. Hydrothermal processing for 40 min and 30 min resulted in the best final weight, weight gain, growth rate, feed conversion efficiency and protein efficiency ratio. The superior performance of hydrothermally processed jack bean over the control is likely a result of the reduction in other ANFs besides the thermostable canavanine. More so, at 27% inclusion level of hydrothermally processed *C. ensiformis* seed, the dietary levels of canavanine could still have been within the tolerable range for *C. gariepinus*. Hydrothermal treatment has been reported to be effective in making feedstuffs more palatable and digestible as well as destroying bacteria and ANFs in the feed (Bell et al., 1980). The present findings agree with various reports that the nutritive value of legume seeds (including cowpeas, lentils, breadfruit seed meal) was improved when subjected to heating (e.g. Kaankula, 1998; Udensi et al., 2007; Wang et al., 2009; Ejidike and Ajileye, 2007). While it is known that boiling of protein supplements may result in denaturation or destruction of the protein (Tamminga et al., 2004; Tiamiyu et al., 2015a), this study demonstrated that hydrothermal processing of *C. ensiformis* for 40 min is not detrimental to fish growth despite significant reduction in some essential amino acids. More so, addition of other high-quality feedstuffs such as soybean and fishmeal is likely to have masked the effect of reduced essential amino acids in the *C. ensiformis* seed meal. In line with the result of this study, Tiamiyu et al. (2015b) demonstrated that boiling watermelon *Citrullus lantanus* seed meal up to 40 min does not affect the protein content or feed utilization by *C. gariepinus*. However, a trial with *Cyprinus carpio* showed significant reduction in performance beyond 30 min of hydrothermal processing (Tiamiyu et al., 2016). The survival results in this study confirmed that inclusion of hydrothermally processed seed meal is not detrimental to the health of *C. gariepinus*.

This study further revealed that the body composition of fish was affected by the inclusion of hydrothermally processed *C. ensiformis* seed meal in the diet. Both the crude protein and lipid content of the fish carcass increased as hydrothermal processing time increased and were higher than the control diet. The nutritional quality of ingested feed is the main factor affecting carcass composition of fish (Reinitz and Hitzel, 1980; Fafioye et al., 2005; Tiamiyu et al., 2015a). The increased levels of lipid observed in this study were in line with other reports on unconventional feedstuff (Chou and Shiau, 1996; Ahmadi, 2004; Pei et al., 2004). Izquierdo et al. (2003) reported that lipid deposition in the liver or muscle of seabass or seabream were not significantly different after feeding an experimental diet with different dietary lipid sources. EL-Marakby (2006) reported similar findings after feeding different oil sources to fish. This result is at variance with the findings of this study. The discrepancies may be attributed to differences in the experimental feedstuff used, target species as well as processing methods of the various feed ingredients.

## 5. Conclusions

This study demonstrated that 40 min hydrothermal treatment of *C. ensiformis* seed meal improves the nutritional value and utilization of *C. ensiformis* by *C. gariepinus* at 27% level of inclusion. Therefore, *C. ensiformis* could be exploited in the commercial and on-farm production of fish feeds to reduce the cost of production of catfish diets. To explore higher inclusion levels, further studies on solvent extraction before hydrothermal processing are recommended since hydrothermal processing alone seems not to be effective in removing canavanine from *C. ensiformis*. Solvent extraction may permit more effective nutrient utilization of *C. ensiformis* beyond the 27% inclusion level used in the present study.

## Relevance of study

Nutritional changes and a significant reduction in most anti-nutritional factors as a result of prolonged hydrothermal processing of jack bean *C. ensiformis* were demonstrated in this study. The growth performance of fingerlings of African catfish *C. gariepinus* was significantly improved with inclusion of hydrothermally processed jack bean meal in the diet compared to diets containing unprocessed jack bean meal. Commercial and on-farm production of catfish diets can employ this method to reduce cost of feed production, as jack bean is cheap and readily available.

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